

J/ψ Production Mechanism Measurements at PHENIX

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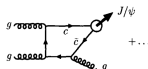
February 15, 2010

Production Mechanism Models

QCD diagrams with \sim non-relativistic J/ψs

Colour-Singlet Model

(Baier,Ruckl,
PLB102,364(1981))



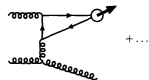
Leading Order Colour-Singlet:

$$g + g \rightarrow c\bar{c}[^3S_0^{(1)}] + g$$

Factorize using $\psi_{c\bar{c}}(r=0)$.

Colour-Octet (NRQCD) Model

(Bodwin,Braaten,Lepage,
PRD51,1125 (1996))



Colour-Octet t-channel Gluon Exchange:

$$g + g \rightarrow c\bar{c}[^1S_0^{(8)}, ^3P_J^{(8)}] + g$$

Factorize using NRQCD matrix elements. $c\bar{c}$ hadronize with a soft gluon

And others... Colour Evaporation Model, s-channel cut, 3-Gluon Fusion, etc.



Colour-Singlet Fragmentation:

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Colour-Octet Fragmentation:

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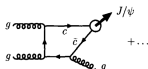
J/ψ was discovered in 1974, but there's still no model or combination of models which satisfactorily describe all measurements

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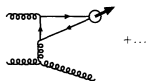
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Constraining the Production Mechanism

Several Measurements:

► Cross-Sections

Rate of production. Typically measured for inclusive J/ψ, but have been measured for direct J/ψs

► Correlation Measurements

Recent Colour Singlet calculations emphasize the importance of c-quark jets produced along with J/ψs (Brodsky and Lansberg – arXiv:0908.0754)

This could be verified by correlating J/ψs with hadrons, e⁺/e⁻, and μ⁺/μ⁻.

► Spin-Alignment

Determine Amplitudes of lepton angular decay distribution

$$\frac{dN}{d\cos\vartheta d\varphi} \propto 1 + \lambda_{\vartheta} \cos^2 \vartheta + \lambda_{\vartheta\varphi} \sin 2\vartheta \cos \varphi + \lambda_{\varphi} \sin^2 \vartheta \cos 2\varphi$$

Measures Density Matrix Elements

$$\rho = \sum_{m,m'} |jm\rangle \rho_{m,m'} \langle jm'|$$

$$W(\theta^*, \phi^*) = \frac{1 + \rho_{00}}{2} (1 + \frac{1 - 3\rho_{00}}{1 + \rho_{00}} \cos^2 \theta^*) + \rho_{1-1} \cos 2\phi^* (1 - \cos^2 \theta^*) + 2\text{Re}(\rho_{01}) \cos \phi^* \sin 2\theta^*$$

- For a more comprehensive discussion of charmonium and bottomonium see talk by C.L. da Silva in session S11.

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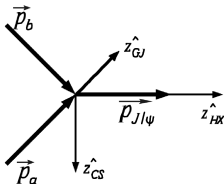
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Reference Frames for Spin-Alignment

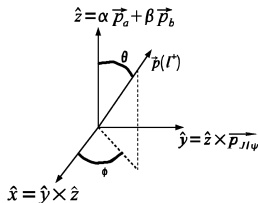
Definitions of ϑ and φ are not unique.



'HX' Helicity (Jacob-Wick)

'GJ' Gottfried-Jackson

'CS' Collins-Soper



\hat{z} and \hat{x} -axes are always in the 'production plane'

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(M. Jacob and G. C. Wick, Ann. Phys. 7, 404 (1959).)

\hat{z} -axis is J/ψ velocity from lab frame

► Gottfried-Jackson

(K. Gottfried and J. D. Jackson, Nuovo Cimento 33, 309 (1964).)

\hat{z} -axis is momentum of one beam boosted into J/ψ rest frame

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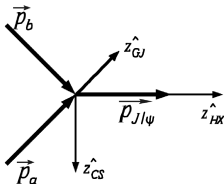
(J. Collins and D. Soper, Phys. Rev. D 16, 2219 - 2225 (1977).)

$$\hat{z} = -\frac{\vec{P}_a}{|\vec{P}_a|} + \frac{\vec{P}_b}{|\vec{P}_b|}$$

where \vec{P}_a and \vec{P}_b are beam momenta boosted into J/ψ rest frame

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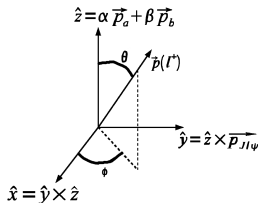
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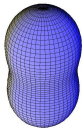
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Measured J/ψ Spin Alignment

$$\frac{dN}{d\cos\theta d\phi} \propto 1 + \lambda_\theta \cos^2\theta^* + \lambda_{\theta\phi} \sin 2\theta \cos\phi + \lambda_\phi \sin^2\theta \cos 2\phi$$

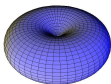
'Longitudinal'

$$\lambda_\theta = 1, \lambda_\phi = \lambda_{\theta\phi} = 0$$

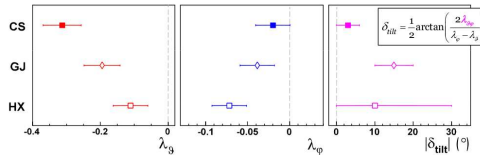


'Transverse'

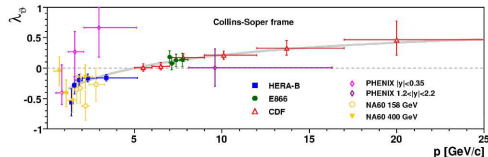
$$\lambda_\theta = -1, \lambda_\phi = \lambda_{\theta\phi} = 0$$



HERA-B Measurements (Eur.Phys.J.C60:517,2009) find quantization axis in CS frame (as pointed out by Lam&Tung in Phys.Rev.D18:2447,1978)



Measurements made of only λ_θ in single frame for each experiment
Rotate all measurements into CS frame

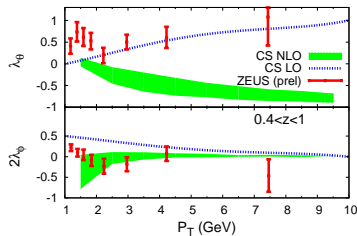
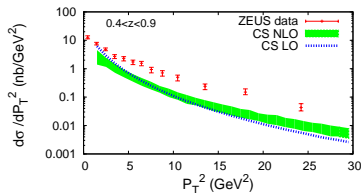


Faccioli, et.al., Phys. Rev. Lett. 102, 151802 (2009)

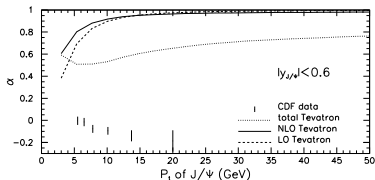
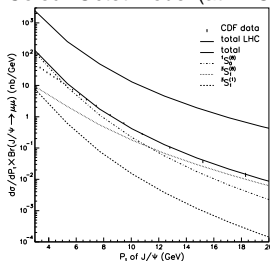
Note: This plot makes a *huge* assumption. It would be much better to measure the full momentum dependence

Cross-Section and Spin-Alignment Measurements

Colour-Singlet Model (at NLO)



Colour-Octet Model (at NLO)

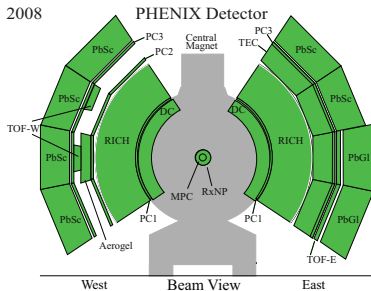


The PHENIX Experiment

High Rate Capability and Granularity with a Sacrifice of Acceptance

Central Arm Electron Detection

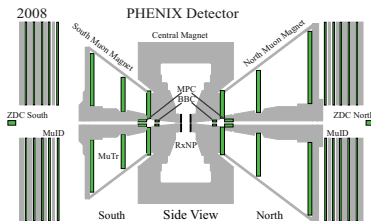
2008



- ▶ Energy Measured in EM Calorimeter
- ▶ Momentum in Drift Chamber
- ▶ $e^+/-$ ID with Ring Imaging Cherenkov Counter
- ▶ $|\eta| < 0.35$, $\Delta\phi = 2 \times \frac{\pi}{2}$

Forward Muon Spectrometers

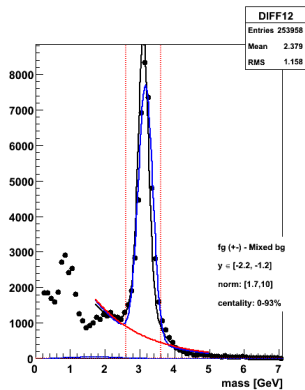
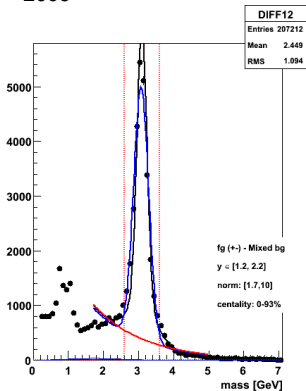
2008



- ▶ Momentum Measured in Cathode Strip Tracking Chambers
- ▶ $\mu^+/-$ ID from Iarocci Tubes interleaved with Steel Planes
- ▶ $1.2 < \eta < 2.2$, $\Delta\phi = 2\pi$

$p + p$ at $\sqrt{s} = 500$ GeV

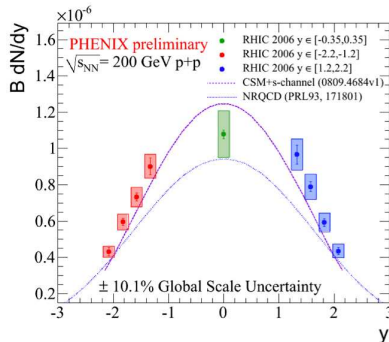
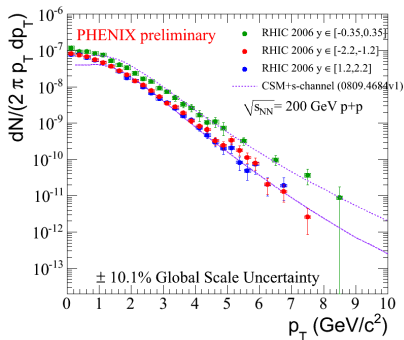
The PHENIX forward muon detectors ($1.2 < |y| < 2.2$) integrated $\sim 10 \text{ pb}^{-1}$ of data in 2009



With many J/ψ s at 500 GeV and a wide momentum coverage, PHENIX can make a major contribution to the production mechanism search

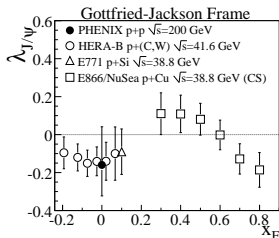
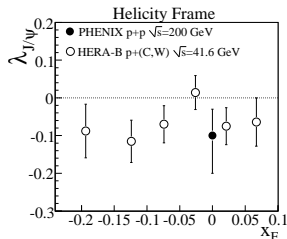
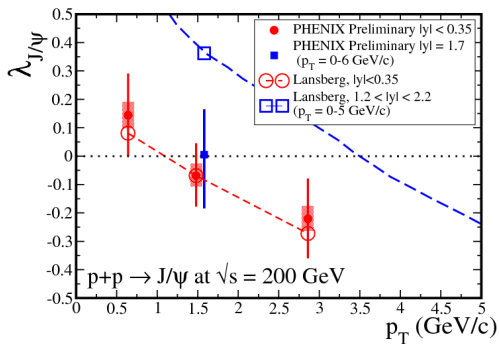
PHENIX J/ψ cross-section measurements

Cross Sections from $p + p$ at $\sqrt{s} = 200$ GeV



Measurements at $\sqrt{s} = 500$ GeV would add another kinematic distribution between RHIC and Tevatron measurements.

PHENIX J/ψ spin-alignment measurements



Measurements currently underway to get forward Spin-Alignments in different frames

Summary

- ▶ J/ ψ s provide access to a wide range of physics, but interpretation requires knowledge of the production mechanism.
- ▶ There are several production mechanisms on the market. None are able to describe all the data.
- ▶ PHENIX has already made a number of measurements contributing to the production mechanism search.
- ▶ RHIC 2009 run provides sufficient statistics for PHENIX to make another significant contribution.

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